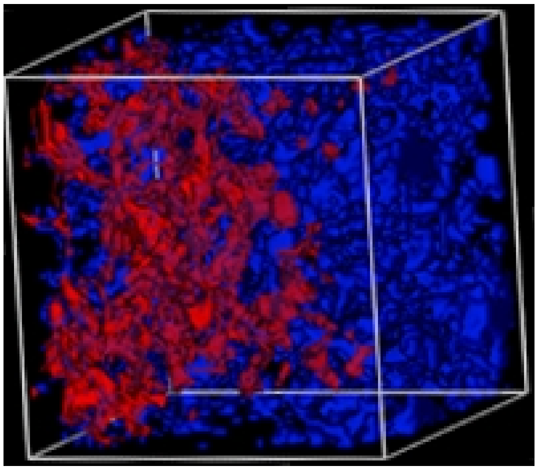
Lattice Boltzmann Permeameter



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Determining if a petroleum reservoir is a viable and economical source of oil, predicting how much oil can be recovered, and configuring a recovery system are done in part through a computer simulation of the entire reservoir. One of the pieces of information that must be input into a reservoir simulation is permeability and relative permeability, which are the primary measures of the ability of the fluids to move in a given porous medium. These measures are critical to making accurate predictions of oil, gas, and water movement in the reservoir. Permeability and relative permeability can be represented either as discrete numerical values or as empirical equations with parameters fitted from laboratory experiments. In either case, extensive, costly laboratory experiments are required, and accuracy is limited to measured data points and within relatively narrow saturation limits.

At Los Alamos National Laboratory, in collaboration with Mobil Exploration and Production Technology Center, we have developed the lattice Boltzmann permeameter, a numerical instrument for modeling relative permeability under a variety of conditions. The permeameter is the only hydrodynamic model designed specifically to calculate permeabilities and relative permeabilities of any pore-space geometry for any set of fluids. It is not based on any empirical assumptions but rather applies known, fundamental physical processes that govern fluid flow for each fluid in a multicomponent system. Our permeameter is faster and less expensive than laboratory permeameters (experiments) and is more flexible in that it offers relative permeabilities for a wider range of fluid saturations and rock characteristics.

Our lattice Boltzmann permeameter won a 1994 R&D 100 Award from *R&D Magazine* for being one of the one hundred most significant technical innovations of the year.

The Invention-Characteristics and Advantages

The theoretical basis for our permeameter is the multiphase lattice Boltzmann method, which has proven to be a valuable tool for studying many hydrodynamic processes occurring within porous media. The lattice Boltzmann method demonstrates that fluid behavior can be simulated through

-,simple movement (advection) and interaction (collision) of “particles” on a grid, or lattice, that defines the pore space. The way these particles are constrained to move and collide is such that when the entire grid is considered, the overall response recovers the exact macroscopic hydrodynamic behavior. Two of the major strengths of this modeling approach are (1) its ability to operate in the complex flow boundaries of a rock pore system and (2) it is particularly well suited for massively parallel computers that can generate the needed calculations extremely quickly.

The most important advantages of our permeameter are its ease of use and flexibility. The flexibility of the lattice Boltzmann approach allows our perineameter to determine relative permeabilities over a wide range of conditions-much wider than can feasibly be considered in a laboratory. Unlike laboratory methods that generally cannot measure very low saturations (less than 10%) or very high pressures, our permeameter can directly measure relative permeabilities over an unrestricted range of saturations and pressures. It also incorporates critical rock/fluid interaction physics that are difficult to implement in the laboratory. Thus, the measured values are much more accurate than those obtained through extrapolation of laboratory data.

Although other numerical methods for modeling fluid flow exist, they sacrifice accuracy for simplicity. Our permeameter models real hydrodynamic behavior, and it recovers the exact equations that describe fluid behavior in the subsurface porous media. The permeameter is able to exactly incorporate all of the inhomogeneities and irregularities of porous media. There are no other computational techniques that can even closely approximate both the complexities of the pore space and the complete characteristics of the fluid/porous media interactions.

Applications

Our numerical permeameter is an application of a new fluid dynamics computational technique to the problem of modeling oil, gas, and water flow in porous media-a capability vital to the US oil and gas industries. Accurate prediction of these flows is critical to the estimation of economically recoverable reserves and the design and implementation of efficient oil and gas recovery processes. Previously, costly and lengthy (about $250,000 over 6 months) laboratory experiments were required to estimate flow models. The permeameter reduces the flow-model development time to days at a cost less than $10,000 and produces more accurate models than traditional laboratory methods. The improved accuracy and much-shortened development time allows oil and gas producers to better assess risks of various reservoir management schemes.

The permeameter is equally applicable to groundwater remediation and the study of reaction kinetics in porous catalysts and fluidized beds. The modeling required for environmental remediation of contaminated aquifers is virtually identical to petroleum recovery for cases of immiscible or slightly miscible contaminants. The flow equations and required permeability information are the same for both fields. The reaction kinetics application is of interest in many fields, including chemical engineering, wastewater treatment, and petroleum refining. A lattice Boltzmann-based computational tool for studying reactive systems has been developed almost in parallel with our permeameter and is expected to be completed toward the end of 1994.

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